Summary of Nitrogen Transport South of Lake Okeechobee - DRAFT

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Summary. At a recent presentation I was asked if the restoration goal of sending more Lake Okeechobee water south was going to adversely impact Florida Bay and associated ecosystems due to the elevated nitrogen concentrations of lake water. Using publically-available data from the South Florida Water Management District (SFWMD) I performed an analysis, as summarized below.

- Water discharged from Lake Okeechobee is not a significant source of nitrogen to Florida Bay, and sending additional water south should improve hydrologic and water quality conditions in the Everglades National Park and Florida Bay.
- Nitrogen levels in water entering the WCAs and Everglades National Park have significantly declined since the 1990s as a result of agricultural BMPs and STA implementation (SFWMD 2019). Studies that rely on nitrogen data collected prior to the recent period and that do not recognize this improving trend can generate erroneous conclusions.
- Water discharged from Lake Okeechobee contains less than 1/3rd the nitrogen concentration of EAA runoff that is sent to the Lake (SFWMD 2018). Lake water constitutes about 22 percent of the surface water that enters the STAs. By contrast, EAA runoff constitutes about 64 percent of the surface water that enters the STAs (SFWMD 2019). Approximately six times more nitrogen is sent to the STAs from the EAA and other regional sources than from Lake Okeechobee (SFWMD 2019).
- The STAs remove about 38% of inflow total nitrogen, including the removal of about 85% of the bioavailable total inorganic nitrogen (Chimney 2018).
- Lake water constitutes about 15 percent of the surface water that enters the WCAs; the proportion of inflow volume attributable to the Lake drops significantly to less than 3% after consideration of rain falling directly on the WCAs (SFWMD 2019). After treatment in the STAs, the nitrogen load from Lake water makes up a very small fraction of the nitrogen entering the WCAs (SFWMD 2019).
- Nitrogen concentrations decline as water moves south from the inflows of the WCAs through Everglades National Park (ENP) and into Florida Bay (SFWMD 2019). Analysis of the spatial trends in nitrogen concentrations from the Lake to Florida Bay indicates that the majority of bioavailable nitrogen entering and within Florida Bay is likely not from sources north of ENP, but rather, from near-field sources, such as the rewetting of organic soil of the ENP exposed during droughts and the decay of submerged aquatic vegetation (Julian 2019).
- Sending additional Lake water to the south should reduce the periods of exposure of organic soils within the ENP, and therefore should reduce nitrogen levels entering Florida Bay.

Background. In the 1970s the state of Florida was sued by the Florida Wildlife Federation for discharging runoff from the Everglades Agricultural Area (EAA) into Lake Okeechobee. This runoff contained high levels of nitrogen, a result of exposing the organic peat soil when the EAA was developed into its present agricultural land use. As a result of this litigation, by the early 1980s the SFWMD had modified the operation of the structures around the EAA, and diverted approximately 90% of the EAA runoff. Other structures along the south rim of the Lake continue to discharge high concentrations of nitrogen into the Lake: S-4, S-236 and the Industrial Canal. In total, the load from the southern region accounted for about 8% of the total nitrogen load to the Lake over the last 5 years (SFWMD 2018). The diverted water contained high levels of nitrogen and phosphorus and was sent south to the Water Conservation Areas (WCAs) and Everglades National Park (ENP), and onto the Gulf of Mexico and Florida Bay. Unfortunately this diverted runoff exacerbated the eutrophication of these downstream water resources. By the mid-1980s the first large scale algae bloom occurred in Florida Bay, and these may have been attributable to a combination of these high nitrogen levels, increased agriculture in the south Dade area, and increased development along the eastern portion of the Everglades (Brand and Maiko 1999). In 1988, the federal government sued the state for discharging high levels of phosphorus to the Loxahatchee National Wildlife Refuge (aka WCA-1) and ENP from the EAA and other sources (SFWMD 2019). Fortunately, the high nitrogen concentration in EAA runoff is diluted by Lake Okeechobee deliveries to the south. Lake Okeechobee water delivered south to the EAA contains considerably less nitrogen (1.5 mg/L) than EAA runoff sent to the Lake (5.7 mg/L; **Figure 1**).

Analysis. Nitrogen levels entering the WCAs have significantly declined since the 1990s as a result of agricultural BMPs and STAs implementation (**Figure 2**; SFWMD 2019). A phosphorus control program at a cost approaching $2 billion is being implemented to lower phosphorus levels through on-farm BMPs and public stormwater treatment areas (STAs). The EAA BMPs have reduced nitrogen loads by 50% compared to the baseline period (SFWMD 2019). The STAs are effective at phosphorus treatment with removal averaging greater than 80%. The STAs also work well in removing bioavailable (inorganic) nitrogen, averaging 85% removal, however, they are not as effective at removing organic nitrogen; the combined total nitrogen removal within the STAs has averaged 38% (Chimney 2018).

Lake deliveries constitute approximately 14% of the total nitrogen load entering the STAs; the remaining 86% comes from the EAA and other regional runoff (see **Appendix** for details; SFWMD 2019). Stated another way, six times more nitrogen load is sent to the STAs from the EAA and other sources than from Lake Okeechobee. After passing through the STAs, the total nitrogen concentration of the combined Lake and regional runoff averages about 1.8 mg/L (SFWMD 2019).

Relative to phosphorus, the dynamics of the nitrogen cycle in the WCAs and ENP are very complex, with exchanges occurring both with the atmosphere and the organic soil. The greater Everglades

ecosystem in general is a phosphorus-limited system, which means the growth of algae and macrophytes are limited by the quantity of phosphorus input into the system – and not nitrogen (SFWMD 2019). When nitrogen is limited, biota can offset this nitrogen limitation through fixation of atmospheric nitrogen gas (N_2; Noe et al. 2001). A gradual reduction in TN concentrations results from the assimilative processes in the marsh as water flows southward (SFWMD 2019). By the time water from WCA-3A enters the Park, the total nitrogen concentration has averaged less than 1 mg/L; further reduction occurs within the Park (SFWMD 2019). A transect of total nitrogen concentrations from the Lake into the Park is presented in **Figure 3**. The state has established water quality standards for nitrogen for the eastern, central and western regions of Florida Bay at 0.65, 0.899 and 0.37 mg/L, respectively (Section 65-302.532, F.A.C.).

Conclusions. Analysis of the temporal and spatial trends in nitrogen concentrations from the Lake to Florida Bay indicates that the majority of bioavailable nitrogen entering and within Florida Bay is likely not from sources north of Everglades National Park, but rather, from near-field sources, such as the rewetting of organic soil of the ENP exposed during droughts and the decay of submerged aquatic vegetation (Julian 2019). Sending additional Lake water to the south should reduce the periods of exposure of organic soils within the ENP, and therefore should reduce nitrogen levels entering Florida Bay.

Figure 1. Comparison of Nitrogen Concentrations

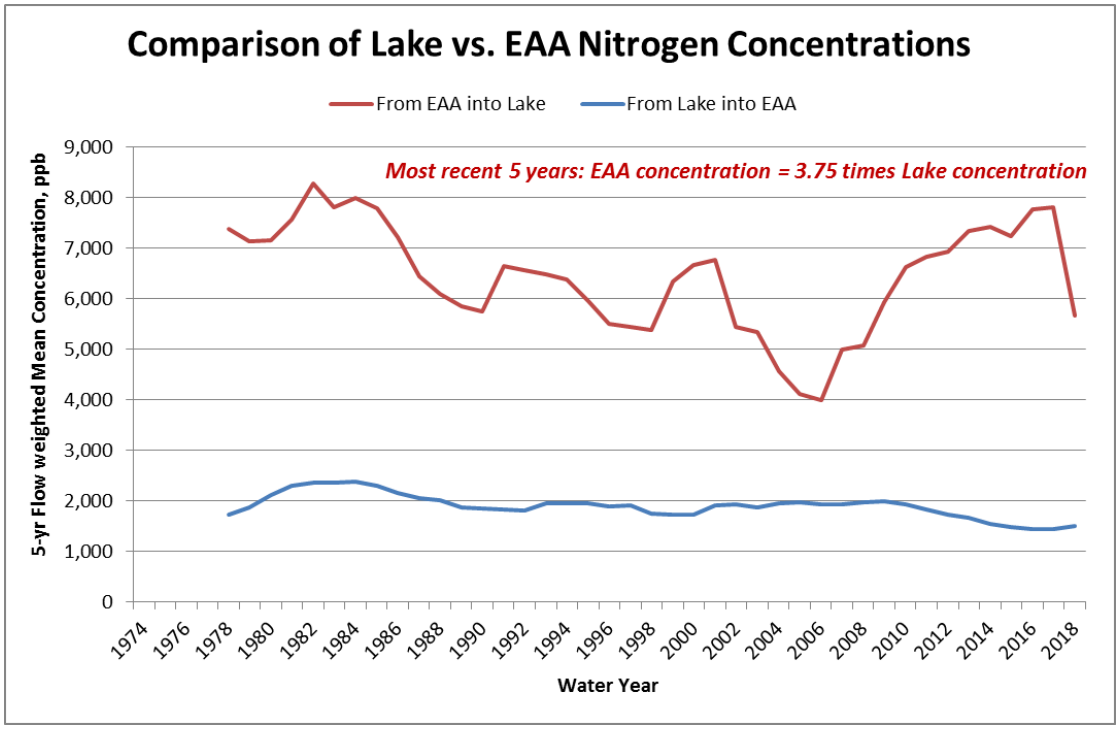


Figure 2. Temporal and Spatial Reductions of Nitrogen in the WCAs and ENP (from SFWMD 2019).

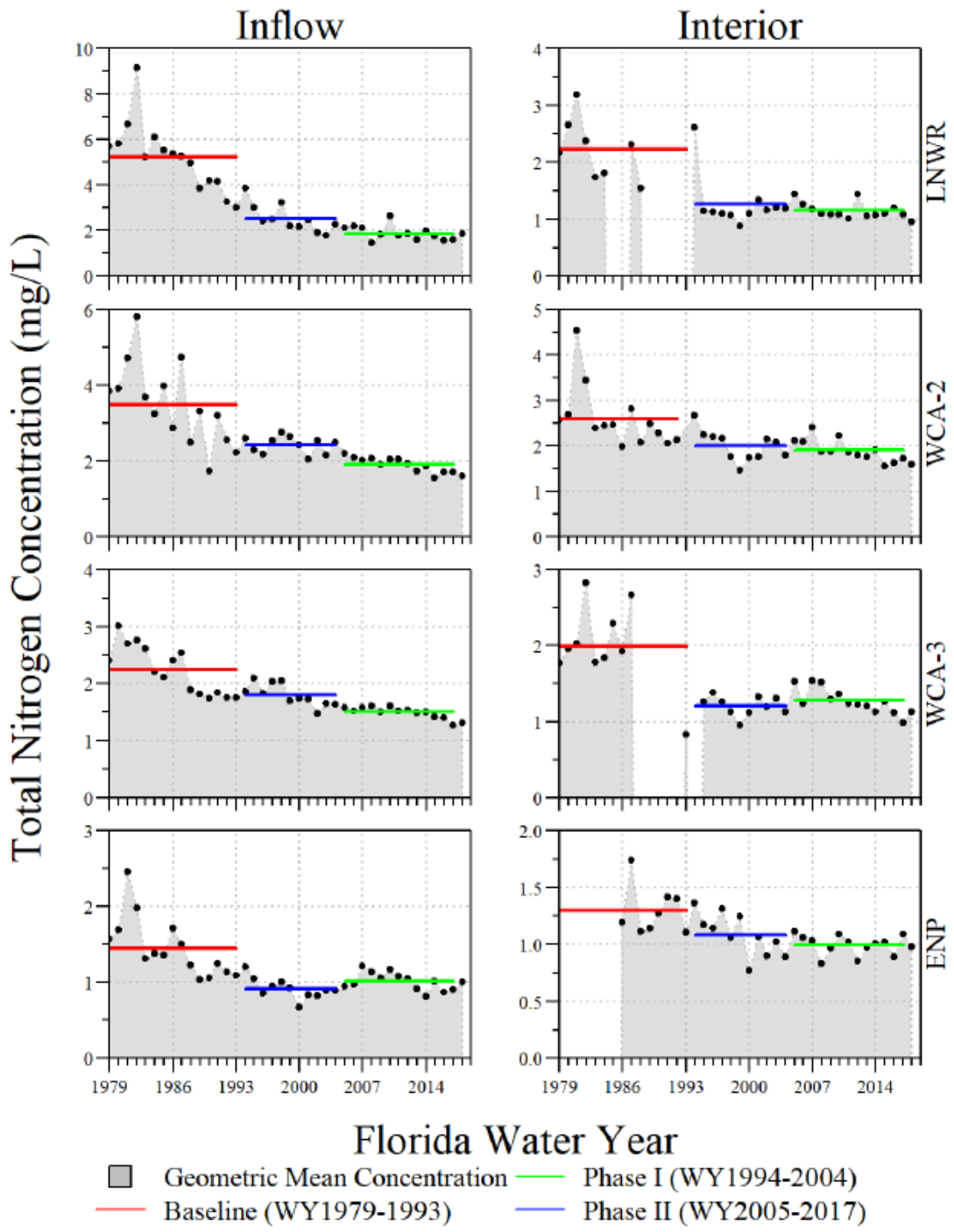
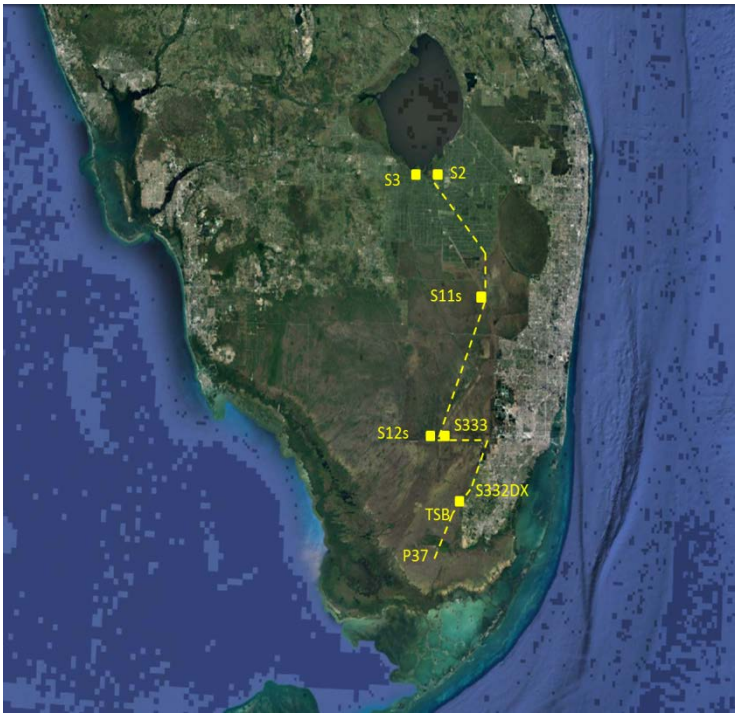
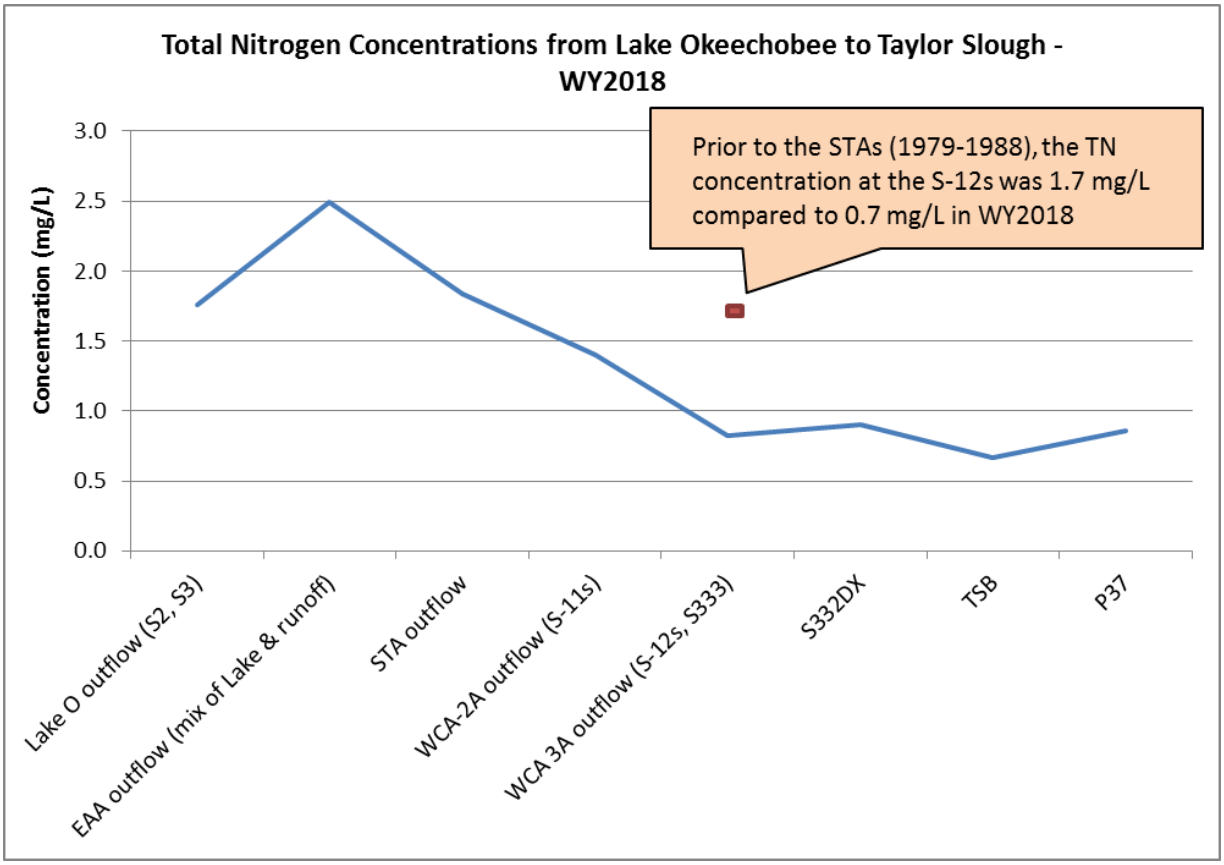


Figure 3A-17. Annual geometric mean TN concentrations for inflow (left) and interior (right) areas of LNWR, WCA-2, WCA-3, and ENP from WY1979 through WY2018. Gray areas under the line indicate geometric mean when corrected for flow. Horizontal lines indicate the mean annual geometric mean TN concentrations for the Baseline (WY1979–WY1993), Phase I (WY1994–WY2004), and Phase II (WY2005–WY2017) periods. (Note: Areas with no gray areas indicate data gaps.)

Figure 3. Total Nitrogen Concentrations South of Lake Okeechobee





Appendix

Water Flows. For the 5-yr period ending WY2018, about 1,341,000 AF/yr entered the STAs prior to being treated and discharged into the WCAs. Of this, about 292,700 AF/yr was Lake water, representing about 22 percent of the total inflow to the STAs.

Discharges from the STAs averaged about 1,398,000 AF/yr to the WCAs. Sources from the east and west contributed an annual average of about 513,000 AF/yr, bringing the total average annual surface inflow to the WCAs to about 1,911,000 AF/yr. The lake contribution (292,700 AF/yr) made up about 15% of the surface inflows to the WCAs, while runoff from the EAA and other sources to the STAs made up 55% of the surface inflows.

Rainfall is estimated to have contributed about 9,600,000 AF/yr to WCA-1, WCA-2A and WCA-3A for the period WY2014-2018, bringing the total average inflow to the WCAs to about 11,512,000 AF/yr. The lake contribution (292,700 AF/yr) made up less than 3% of the total inflows to the WCAs, while runoff from the EAA and other sources to the STAs made up 9% of the total.

After accounting for evapotranspiration and other losses, the SFWMD estimated the 5-yr average annual outflow from WCA-3A to the ENP from the north was about 905,000 AF/yr. It is impossible to track individual water molecules from the lake through the WCAs into the park, and in fact, it is difficult to say that any lake water made it through the nearly 750,000-acre WCA-1, WCA-2A and WCA-3A; all of it could have been lost to evapotranspiration. However, an upper end estimate could be developed by assuming the same percentage of inflows attributed to the lake (3%) applies to the outflow from the WCAs. This suggests that about 23,000 AF/yr of lake water entered the ENP from Lake Okeechobee. This represents about 3% of the surface inflows to the Park from the north. An additional 291,000 AF/yr entered the ENP from Taylor Slough and the Coastal Basins, bringing the total surface inflow to about 1,196,000 AF/yr.

Rainfall on the freshwater portion of the ENP historically averaged about 54.55 in/yr (SFWMD 2019), contributing about 18,759,000 AF/yr; bringing the total inflow to ENP to about 19,955,000 AF/yr. Of this, it is estimated that lake inflow (24,000 AF/yr) made up about 0.1% (about one tenth of one percent), while runoff from the EAA and other sources to the STAs made up 0.4% of the total inflows.

Total Nitrogen Levels

Using data from SFWMD, **Figure 1** compares TN concentrations entering the Lake from the EAA against TN concentrations leaving the Lake to the EAA (SFWMD 2018b). For the most recent 5-yr period, concentrations entering the Lake from the EAA (5.68 mg/L) were almost 4 times higher than concentrations leaving the lake (1.51 mg/L). **Figure 3** compares the TN concentrations along a

north-to-south transect from Lake Okeechobee to the southern section of Everglades National Park just north of Florida Bay (data from SFWMD DBHYDRO, downloaded 3/27/2019).

The 5-yr flow-weighted mean TN concentration of lake water released to the south was 1.51 mg/L. About 292,700 AF/yr of Lake water entered the STAs, hence the estimated 5-yr average TN load to the STAs from the Lake was about 546,000 kg/yr. The average TN concentration entering the STAs from all sources was about 2.36 mg/L, and when combined with a 5-yr average inflow of 1,341,000 AF, yields an average annual load of 3,907,000 kg/yr. Of this, the 546,000 kg/yr from the Lake represents about 14% of the TN load to the STAs. STAs are effective at removing dissolved inorganic nitrogen (DIN), but not dissolved organic nitrogen (DON). The estimated average TN removal within the STAs is about 38% (Chimney 2017). Using this estimate of removal suggests the TN load from the Lake to the WCAs averaged about 339,000 kg/yr.

The average TN concentration leaving WCA-3A and entering the Park was 0.83 mg/L; allowing one to estimate the TN load from the lake to the Everglades National Park at about 23,400 kg/yr. By contrast, using the same set of assumptions leads to an estimate of 83,900 kg/yr of TN to the Park from the EAA and other sources to the STAs. Further reductions in TN concentrations are observed during conveyance through the ENP to the Gulf of Mexico and Florida Bay. Lack of sufficient sampling locations precludes a calculation of TN loads from Lake Okeechobee that make it the final path into the Gulf of Mexico and Florida Bay, although a "worse case" scenario estimate may be that lake water contributes less than 2.5% of the TN relative to the other surface sources of TN into ENP. A similar estimate for TN loads from the EAA and other sources to the STAs is on the order of 9%, more than 3 times the loading from the lake.

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